LCA in Japan

Current Status of Weighting Methodologies in Japan

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Abstract. In Japan, requirements for the development of valuation methodology are very stringent. Several methodologies have been proposed to meet these demands in recent years. These methods, however, are quite different in many points such as selected impact categories, the numbers of substances considered, and basic concepts for the environment. The results of LCA are fully dependent on the goals of LCA practitioners and commissioners. If they misunderstand the concept of method and use it, the result may not fit for the purpose. Consequently, it is important to characterize the methods selected by the practitioner in accordance with their LCA goals. In this paper, weighting methodologies proposed in Japan have been introduced with a comparison between the results of case studies for common industrial products. Furthermore, we considered the present situations and future directions of valuation methodologies in Japan. This consideration is carried out based on the results of investigations performed by the Impact Assessment Committee of the National LCA Project of Japan.

Keywords: Case studies; consumption of time; distance to target (DtT); industrial products; LCA practitioners; LCA commissioners; LCIA; Life Cycle Impact Assessment; National LCA Project of Japan; valuation; weighting

Introduction

LCA (Life Cycle Assessment) has been applied as the environmental burden or impact assessment methodology for industrial products and is recognized to be the key tool of environmental management in the ISO-14000 series.

According to ISO 14040 (Life Cycle Assessment – Principles and framework), the framework of LCA is composed of 1) Goal and scope definition, 2) Inventory analysis, 3) Impact assessment and 4) Interpretation. The third step or impact assessment is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis (ISO 14040, 1997). This step includes the following elements,

1) Assignment of inventory data to impact categories (classification)
2) Modeling of the inventory data within impact categories (characterization)
3) Possibly aggregating the results in very specific cases and only when meaningful (weighting)

In ISO/DIS 14042 (Life Cycle Assessment – Life Cycle Impact Assessment), it is stated that the third element or weighting, which is an optional element due to this step, is based on value choices and not on natural science (ISO/DIS 14042, 1998). Consequently, weighting is not allowed for comparative assertions disclosed to the public. However, the result of weighting may be calculated into a single index that facilitates an interpretation of the result. Especially in Japan, the demands for developing the weighting methodology that enables the assessment of Japanese industrial products are very stringent. From this background, several methodologies have been proposed to meet these demands in recent years. However, these proposed methodologies are entirely different in equations for calculation, considering impact categories, the numbers of environmental substances involved, and even the basic concept of the environment. The results of LCA are dependent on the goals of LCA practitioners. Furthermore, the involvement of subjective judgments or value choices in weighting by the developers of this method will be unavoidable. Consequently, it is quite important for LCIA practitioners to understand the characteristics of weighting methodologies to select the method in accordance with their goals of LCA. There is little information that presents the characteristics and differences between weighting methodologies to the LCA practitioners in Japan. Considering this background, the impact assessment study committee of the National LCA Project in Japan has surveyed the weighting methods proposed in Japan through case studies of industrial products in order to obtain information. In this paper, we introduced the concepts of several methods proposed in Japan and characterized the strong and weak points in methods based on the results of investigations performed by the committee. Furthermore, we described the future directions of weighting in Japan to improve the quality of assessment.

1 Weighting Methodologies Proposed in Japan

The history of the development of impact assessment in Japan is not very long. In the past, case studies of LCA, including LCIA, were apt to use European methodologies for

Japanese products. However, the impacts of photochemical oxidants by emission of hydrocarbon, for example, are quite dependent on the area where they are emitted (like the center of a city). Consequently, it is essential to develop methods that consider Japanese backgrounds to estimate the environmental impacts in our country exactly. For this reason, and in Japan as well, some researchers proposed the following methodologies in recent years:

1. Site-specific considerations for local impact categories (MATSUNO, 1998 a,b)

Concerning the global impact categories, no considerations have been taken for areas where emission occurs. On the other hand, in the event of the local impact categories, regional aspects are considered and subdivided into local areas like prefectures and sea areas.

2. Consumption of time (YASUI, 1998)

The impacts are interpreted into the consumption of time for environmental crisis. Weighting factors are defined with the considerations of fatality and periods for crisis.

3. Panel approach (NAGATA, 1996)

Weighting factors are determined by the results of questionnaire considering the differences between the groups of respondants.

4. I-O integrated (ITSUBO, 1998; ITSUBO, 1999)

Impact categories are divided into 2 subcategories, input related and output related, and established simplified damage functions respectively as a prior step of aggregation to single index.

We would like to characterize these methods of weighting as follows.

2 Comparison Between the Methodologies Proposed in Japan

2.1 Safeguard subjects

Safeguard subjects are nothing more than elements of the natural environment which are intrinsically considered to be worth being protected. A definition of safeguard subjects in weighting concepts is quite important information to help practitioners understand the background of the method and the meaning of the environment itself. Consoli et al. proposed 'resource depletion', 'human health' and 'ecological health' as protection areas (CONSOLI, 1993). Beltrani recommends 'human health', 'natural and semi-natural habitats' and 'natural resources' (BELTRANI, 1997). These proposals are not directly associated with the weighting method, but with concepts. Within the practical approaches, Eco-Indicator'95 proposed 'human health' and 'ecological health' (GOEDKOOP, 1995). In a new version of the Eco-Indicator approach, 'the resources base' has been added (GOEDKOOP, 1998). EPS considered 'biodiversity', 'natural resources', 'human health', 'economical productivity' and 'aesthetic values of nature' (STEEN, 1996). During the last year, Udo de Haes et al. proposed the very similar concepts of 'human health', 'natural environment', 'natural resources' and 'manmade environment' as areas of production (UDO DE HAES et al., 1999).

In Japan, Nagata considered the five safeguard subjects to be the same as the EPS system and compared the importance by questionnaire. These results don't reflect the result of weighting, because weighting will be given by the relationships between the impact categories not safeguard subjects. Yasui and Itsubo considered 3 subjects, 'human health', 'ecological health' and 'resources.' Matsuno does not clearly define the safeguard subjects. In this method, however, impact categories that effect human health and the ecosystem have been considered. These 2 subjects are involved implicitly as safeguard subjects.

2.2 Impact categories and substances considered

Generally, the numbers of substances considered in inventory analysis is large. Substances related with ozone layer depletion, for example, are composed by CFCs like CFC-11, halons, HCFCs and more than ninety can be counted in total. It is needless to say anything about toxicity substances. It is difficult to involve all of environmental loading substances in the impact assessment.

There are a lot of problems associated with environment-related greenhouse effects, acidification, and resource depletions. We are familiar with these environmental problems through the media. Consequently, most of the procedures of impact assessment classify substances into these problems, or impact categories. Table 1 summarizes the impact categories available in methodology. Matsuno considers 3 categories as global and regional impacts, and 3 categories as local impacts. Nagata established 9 categories. In this method, 'Water pollution' and 'Air pollution' are included instead of eutrophication and photochemical oxidants, etc. The characterization factors concerning eutrophication and photochemical oxidants were based on the report by Heijungs et al. (HEIJUNGS et al., 1992). In contrast, the characterization factors for 'air pollution' and 'water pollution' are originally defined by the developer of the method, such as the inverse of environmental standards in Japan. Practitioners should also take into consideration the fact that the characterization factors depend on the way of selecting the impact category. Nagata and Itsubo divided problems related with resource depletion into 2 categories like energy resources and mineral resources. Yasui divides the category concerning human toxicity into 'heavy metals' and 'carcinogenic substances'. This approach is similar with Eco-Indicator'95 which is subdivided into several categories like carcinogenic substances and heavy metals. The ranges of toxicity substances are comparatively broad. If we treat human toxicity as one category, it is difficult to classify the type of disease. How one can involve this seriousness of disease into details should also be investigated.

From the comparison between these concepts, the categories that have an effect on human health and ecological health are commonly included. On the other hand, the categories concerning resources are dependent on methodologies.

Udo de Haes et al. proposed a list of impact categories (UDO DE HAES, 1996). They are divided roughly into 2 parts, input-related like biotic resource and output-related like greenhouse effects. It can be estimated that resource depletion should be considered as an impact category in order to meet a worldwide consensus. Furthermore, Japan has very few resources so that the problem of resource depletion should be more

emphasized than in other countries. In contrast, because the question of how to assess the effect of resource depletion is still open, some idea may arise that should not include this problem into the total system. Resource depletion should be involved in weighting as an impact category, but the procedure for assessment is premature. We can describe the issue of land use and waste in similar discussions. There is no method that involves the effect of land use. On the other hand, Nagata and Yasui consider the effects by waste. If we interpret that the increase of waste led to an exploitation of the land, their methods involve the impacts of land use indirectly.

LCA practitioners should understand this background, and select a method that suits their goals and criteria as far as possible such as an inclusion of the environmental problems or the reliability of an assessment.

2.3 Weighting procedure across impact categories

The aggregated single indicator should be generalized considering environment impacts since the result may involve the effects to human health and ecological health. Consequently, subjective judgement is unavoidably introduced in weighting. In ISO14042/DIS, weighting is treated as an optional element. Based on Hoffstetter (HOFFSTETTER, 1996), Lindeijer (LINDEIJER, 1996) existing weighting methods can be classified into 5 groups,

(1) Proxy
(2) Technology
(3) Monetarization
(4) Distance to Target (DtT)
(5) Panel approach

Matsuno and Itsubo propose one of the types of DtT approach. Nagata's approach belongs to the panel method. There are no approaches which belong to Yasui's proposal. The equation for calculation in Matsuno's approach is expressed as follows:

Matsuno classified impact categories into 2 groups from the geographical range of effect, global and local. Global groups include acidification considered as a regional category. The impacts included in this group are estimated as the following formation:

$$I = \sum_i \frac{E_i}{N_i} \times F_i \qquad (1)$$

$$F_i = \frac{A_i}{T_i}$$

with
I: Single index
E_i: The inventory data of impact category i emitted through the life cycle of product
N_i: Annual effects of impact category i in a certain area (normalization value)
F_i: Weighting factor of impact category i
A_i: Present situation of impact category i in a certain area
T_i: Target value of impact category i in a certain area

In the assessment of local groups, weighting factors can be obtained by the considerations of a population in an objective area. Factors are defined for each substance.

$$I = \sum_{i,j} \frac{E_{ij}}{N_{ij}} \times F_{ij} \qquad (2)$$

$$F_{ij} = \frac{C_{ij}}{C_{0ij}} \times \frac{P_j}{P}$$

with
E_{ij}: Inventory data of substance i emitted at area j
N_{ij}: Annual emission of substance i at area j (normalization value)
F_{ij}: Weighting factor of substance i at area j
C_{ij}: Present concentration of substance i at area j
C_{0ij}: Environmental standard of substance i at area j
P_j: Population at area j
P: Population of Japan

In this method, weighting factors are expressed as a ratio between target value (environmental standard in Japan) and present value. The characteristics of this method are that impact categories are divided into 2 groups and weighting factors and normalization values are estimated at every geographical area like a prefecture for local impact categories such as photochemical oxidants, eutrophication, human toxicity.

Itsubo proposed the following equation for weighting.

$$I = \sum_k W_{output} D_{k-output} \sum_i \frac{E_i}{N_i} F_i + W_{input} D_{k-input} \sum_r \frac{E_r}{N_{J,r}} \times \frac{\frac{N_{G,r}}{R_r}}{100} \qquad (3)$$

with
I: Single index(%)
W_{output}: Weighting factor of safeguard subjects concerning (human health and ecosystem)
W_{input}: Weighting factor of safeguard subjects concerning input related (resources)
$D_{k\text{-}output}$: Damage of safeguard subjects (human health or ecological health) in the case that the present environmental impacts are equal to target value. (%)
$D_{k\text{-}input}$: Damage of safeguard subjects (resources) in the case that the present environmental impacts are equal to target value (%)
E_i: Incremental effects of impact category i caused by product
N_i: Normalization value of impact category i
F_i: Weighting factor of impact category i
E_r: Consumption of resource r through the life cycle of product. (ton/year)
N_{jr}: Annual consumption of resource r in Japan (ton/y)
$N_{G,r}$: Annual consumption of resource r in world (ton/y)
R_r: Confirmed resource base of resource r (ton)

The characteristic of this method is to establish the simplified damage functions of impacts related with inputs and outputs, respectively. In this concept, it is important to distinguish with the comparison between impact categories and safeguard subjects. Comparisons between impact categories are proposed by the developer of a method considering political standards. Comparison between safeguard subjects can be introduced

by LCA practitioner based on their goals, because this is fully dependent on the practitioner's subjectivity.

Nagata estimates the environmental impacts from these following equations:

$$A_j = \sum_k (C_{j,k} \times TQ_k) \tag{4}$$

$$ELF_k = \sum_j (C_{j,k} \times W_j / A_j) \times 10^6$$

$$ELP_i = \sum_k (ELF_k \times Q_{i,k})$$

with

ELP_i: Aggregated single indicator (environmental loading points) by product

A_j: Annual effects of impact category j (normalization value)

$C_{j,k}$: Characterization factor of substance k in impact category j

TQ_k: Annual emission (or consumption) of substance (or resource) k

W_j: Weighting factor of impact category j

ELF_k: Environmental loading factor of substance (or resource) k

$Q_{i,k}$: Emission or consumption by product i (inventory data) (kg)

In this method, weighting factors can be obtained from the results of a questionnaire. The questionnaire has been conducted by a lot of groups such as LCA practitioner, environmental scientist, students and so on. Nagata compared the results between the results of these groups and describes that the results in Japan differ greatly from that of European scientists (NAGATA, 1999).

Yasui established the weighting factors from the ratio between the 'fatality' and the period of crisis

$$F_i = \frac{\text{Fatality}}{\text{Years}} \tag{5}$$

with

F_i: Weighting factors of impact category i

Fatality: Seriousness of crisis

Years: A period of environmental crisis

Fatality has no dimension, since the dimension of the weighting factor is inverse with that of time. The result prior to weighting is expressed as time, because the result of characterization is divided by a normalization value, expressed in effect value per one year. Consequently, the result of weighting will be dimensionless. The components of weighting factor, fatality and years are not supposed to be defined by the developer, but by the LCA practitioner. However, Yasui provides an example of factors for practitioners.

3 Calculated Results

Last year, one of the committees of the National LCA Project in Japan, the impact assessment study committee surveyed the weighting methods in Japan which have been proposed and applied based on common inventory data in order to characterize them respectively. The inventory data applied is related to an imaginary copy machine.

The modeled life cycle stages of the system include the exploitation resources, the manufacturing components, the final assembly of the product, the use phase and, finally, the end of life phase without recycling aspects where the product is landfilled. The emissions of after landfill were neglected because of the lack of time for the investigation. The inventory data was collected by Finkbeiner et al. (FINKBEINER, 1998) based on the preliminary data by Japan business machine maker association. In this paper, the results by Nagata, Yasui and Itsubo have been compared. We did not apply Matsuno's approach, because more geographical information in inventory data is required to apply this method.

Calculated results were shown as follows:
The results of weighting classified into life cycle stages are compared in Figure 1. They share certain similarities in that the stage of usage is dominant in the life cycle of the imaginary photocopier machine. The result of Yasui's approach is different from others in that the contribution of end of life is estimated higher, comparatively. On the other hand, Itsubo showed that the ratio of manufacturing is higher than the other 2 results. We see from **Fig. 1** that the end of life stage is not serious. This is mainly due to the scenario of the disposal of products. If we can include the inventory after landfill or incineration into the boundary, the result may be changed.

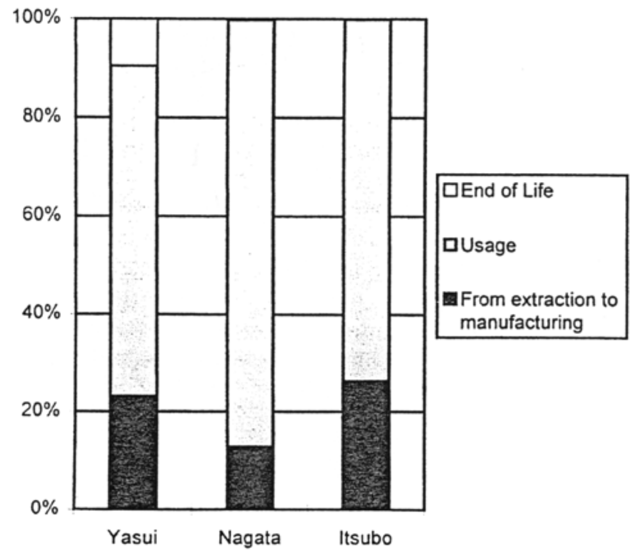

Fig. 1: Comparison between the results of weighting, the contribution of life cycle stages in life cycle of imaginary copy machines

Fig. 2 shows the comparison of the contributions of impact categories in aggregated results. This result differs from that of Figure 1 in that the compositions are quite different between the 3 methods. According to Yasui's approach, the problem of waste proved to be very serious. In this method, both components of waste and total weight have been considered; here, especially the effect to the lack of space for landfill is emphasized.

The result of Nagata's method showed that the effect by water contamination is dominant. The other impact cat-

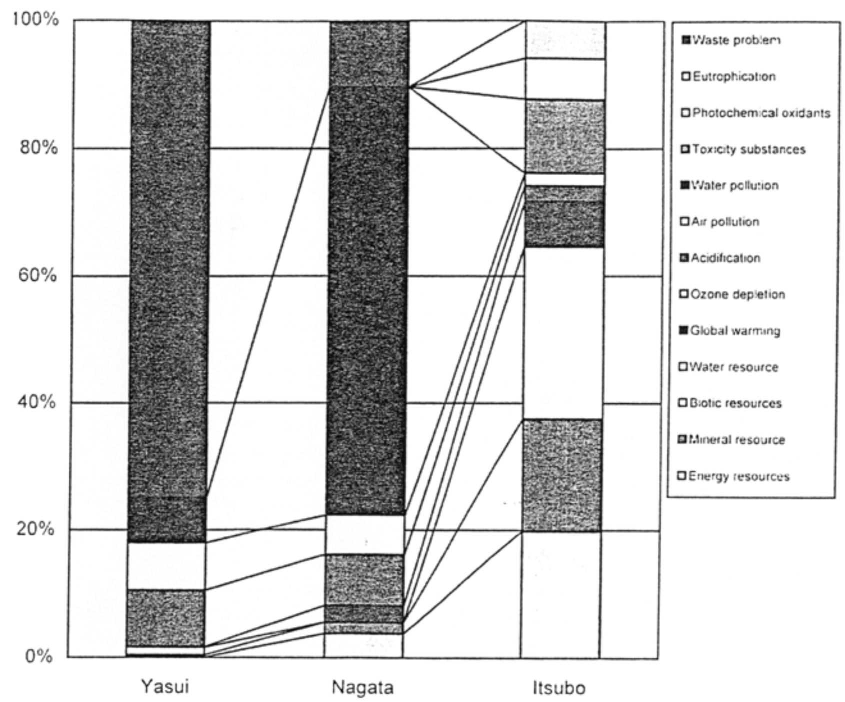

Fig. 2: Comparison between the results of weighting classified into the impact categories. Itsubo assumed that the effects of 'Air pollution' consider all substances except for photochemical oxidants and chemical substances. 'Water pollution' is an impact other than eutrophication. Nagata and Yasui treated them in one category such as 'Air pollution' and 'Water pollution'

egories like waste problem, acidification and air pollution are important, but contributions of these categories are less than 10 percent of the total impact of a product.

From the result of Itsubo's approach, the impacts of consumption of energy, biotic resources and abiotic resources are comparatively larger. The value of biotic resources is due to the consumption of lumber to produce paper involved in the usage stage. In output related categories, it suggests that the effect of toxicity substances and greenhouse effects are important comparatively, although the other 2 approaches showed them to be negligible. Nagata and Yasui considered the local impact categories like waste problems, water pollution and air pollution to be important. In contrast, Itsubo considered the global impact categories like resource depletion and greenhouse effects to be very serious.

Fig. 3 illustrates the comparison between 3 approaches classified into environmental substances. This figure also shows that the compositions are entirely dependent on method-

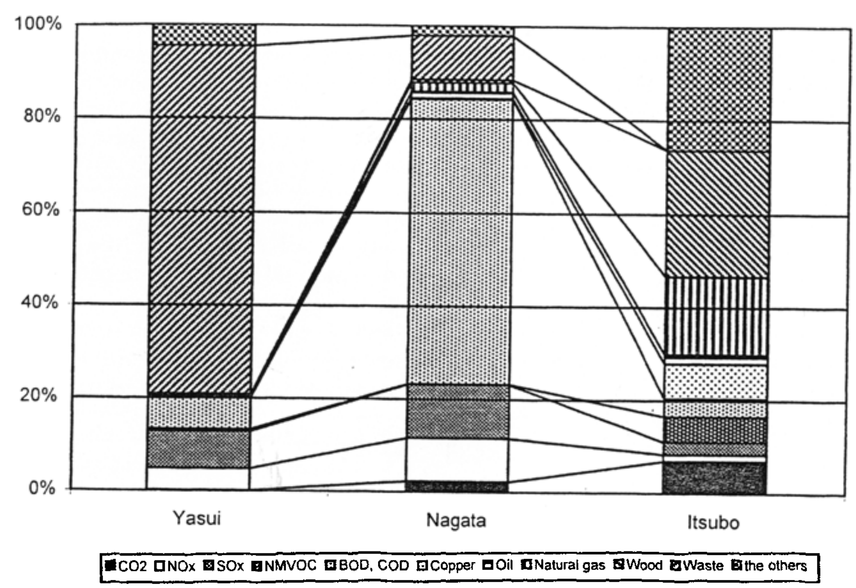

Fig. 3: Comparison between the results of weighting classified into environmental loading substances and resources.

Table 1: List of weighting methodologies developed in Japan

Method	Site-specific Consideration	Time Consumption	Panel	I-O Integration
Developer, Organization	**Matsuno, Inaba (NIRE)**	**Yasui (University of Tokyo)**	**Nagata (Waseda University)**	**Itsubo, Yamamoto (University of Tokyo)**
Safeguard Subjects	(Human health) (Ecological system)	Human health Impacts on ecological system Resource consumption	Human health Soundness of ecological system Protection of resources Future production Aesthetic value	Human health Decline of ecological system Resource depletion
Impact Category	Global warming Ozone depletion Acidification Human toxicity impacts Generation of photochemical oxidants Eutrophication	Global warming Ozone depletion Acidification Air pollution Heavy metal pollution, carcinogenic substance pollution Water pollution Water resource consumption Energy consumption Mineral resource consumption Solid waste	Global warming Ozone depletion Acidification Air pollution Marine water pollution Impacts on ecological system Energy depletion Resource consumption Waste treatment problems	Global warming Ozone depletion Acidification Air pollution (except for oxidants) Photochemical oxidant formation Carcinogenic substances Water pollution Eutrophication Depletion of energy resources Depletion of mineral resources
Fate Analysis	–	–	–	–
Impact categories and the number of substances considered in assessment	Global warming (10) Ozone depletion (8) Acidification (2) Eutrophication (3) Generation of photochemical oxidants (2) Human toxicity impacts (3) **Total substances: 28**	Global warming (9) Ozone depletion (5) Acidification (2) Air pollution (7) Heavy metal pollution, carcinogenic substance pollution (14) Water pollution and eutrophication (7), water resource consumption (1) Energy consumption (4) Mineral resource consumption (11) Solid waste (15) **Total substances: 75**	Raw materials (34) Emission to atmosphere (11) Emission to water areas (2) Solid waste (1) **Total substances: 48**	Global warming (12) Ozone depletion (5) Acidification (5) Eutrophication (3) Photochemical oxidant formation (2) Carcinogenic substances (12) Air pollution (2) Water pollution (23) Depletion of energy resources (4) Depletion of mineral resources (20) **Total substances: 88**
Method of defining Weighting factors	DtT	At discretion of assessor	Questionnaire survey	DtT
Unit	Dimensionless	Dimensionless	Dimensionless	Dimensionless

ologies. As shown in Fig. 2, the result by Yasui showed that the effect of waste is dominant and accounts for more than 70%. From Nagata's result, the impacts caused by the emissions of BOD (biotic oxygen demands) and COD (chemical oxygen demands) occupied about 60%. According to Itsubo's approach, the impacts by the consumption of lumber, and that of natural gas and the emission of CO_2 are estimated as being dominant. Furthermore, the other substances shown in Fig. 3 account for more than 20%.

4 Problems and Future Directions

Weighting methods proposed in Japan have been introduced in this paper. The characteristics of these methods are summarized in **Table 1**. They differ entirely from the safeguard subjects, impact categories, and involving substances considered except for the fact that the calculated results are expressed as being dimensionless. Recently, more attention has been paid to studies to develop the method that estimate environmental impacts as external cost, such as ExternE and EPS. In Japan, Akai also tried to estimate the cost by CVM (Contingent Valuation Method) that is associated with a supposition of physical impacts (AKAI, 1999). This enables one to express the damage clearly, like the number of deaths. So far, however, because of the lack of information (such as from pathology), the assessments for only SPM and NOx are available. Eco-indicator'98 estimated the damages of safeguard subjects like human health. Judging from these tendencies, the studies for estimating real impacts or physical impacts should be increased. However, it is essential to reflect the knowledge of every environmental specialist in order to accomplish these studies. Within this year 1999, a committee that aims at establishing the damage functions has been launched by the National LCA Project of Japan.

As shown in Table 1, all of the methodologies do not include a fate model that estimates the relationship between the emission rate and concentration of components like air and water. In Japan, there are no tools like EUSES (JAGER et al., 1996) in Europe and CalTOX (McKONE, 1993) in USA that can be used for LCIA as a standard. It is of great significance in Japan to develop a fate model that can be involved in LCIA.

It is important to consider the geographical information in LCIA, especially for site-specific problems. Matsuno proposed a method that subdivides Japan into prefectures and showed a result that differs entirely between a city area like Tokyo and a background area like Hokkaido.

Finally, it is essential to correspond with inventory data. Currently, inventory data in Japan is restricted to several sub-

stances like CO_2. However, there is no doubt that the assessment is required to include as many substances as possible, such as chemical substances. There are no methods in Japan that are available for more than one hundred substances. Consequently, it is important to develop the method that is applicable for most environmental loading substances, as far as possible.

Internationally, impact assessment is now in a developing stage. Subjective judgement by the developers of procedures or LCA practitioners will unavoidably be introduced in weighting process and it would take time to meet a consensus to a certain degree. Currently, the improvement of transparency and reliability, and correspondence with an inventory database are quite essential in Japan and studies are required for the development of the advanced methodology of assessment for environmental impacts considering the problems noted above.

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